Novel Display Technologies for Accelerating Scientific Discoveries

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Figure 1: Collocated and remote collaboration using a high-resolution tiled display

1 Introduction

From cathode ray tube (CRT), to liquid crystal display (LCD), to organic light-emitting diode (OLED) displays, the computer monitor has been used worldwide by millions—if not billions—of scientists to gain insights and discoveries. However, due to the unprecedented surge in data resolution, and display and interaction limitations of traditional monitors, scientists are missing key observations. Next-generation novel visualization display technologies such as high-resolution tiled displays and Head-Mounted Augmented and Virtual Reality (AR/VR) Displays play important roles in DOE's mission science as they could potentially enable scientists to collaborate and explore their data more intuitively, thus accelerating key discoveries.

2 Identified Opportunities

Fostering collaboration and breakthrough scientific discoveries. Breakthrough science, and especially DOE mission science, requires scientists crossing disciplinary boundaries and collaborating on big mind-bending problems. However, having a group of multi-disciplinary scientists huddled around a computer monitor is not the ideal collocated collaboration medium. The screen is physically too small, has very low resolution–in contrast to high-resolution datasets–and can only be controlled by a single person. Furthermore, big multi-disciplinary teams might be scattered around the globe, and as a result, new remote collaboration methodologies are needed. On the other hand, tiled displays are high resolution, can visualize big data, and allow multiple scientists to gather in a room, work collaboratively, and make scientific discoveries (Figure 1). Similarly, AR and VR displays allow exploration of datasets in the third dimension, while enabling remote collaboration.

Harnessing the immersive power of Augmented and Virtual Reality. Historically, domain scientists analyze and explore their multi-dimensional data on two-dimensional computer monitors. The vast majority of their data sits outside of their monitor's viewport, however, as they can only see a cropped two-dimensional projection of it. And while increased resolution should allow them to observe a phenomena in greater detail, the limitations of the monitor leads to missed discoveries and opportunities. Conversely, AR/VR enables the user to take a leap into the third dimension, and use their own body to pan, zoom, and rotate around their data. In other words, it allows immersive data exploration and manipulation of complex multi-dimensional datasets, thus giving unprecedented insights. *"Immersing the user in the solution, virtual reality reveals the spatially complex structures in computational science in a way that makes them easy to understand and study"* [2]. With VR, scientists can walk around their data while manipulating it intuitively using their own hands. In addition to the traditional visualization of physical spaces - the additional visual capacity of VR lends itself to opportunities in new areas of representation of AI model/feature space. Similarly, AR will allow natural interaction with the data, as they can move, rotate and interact with the physical object directly, while the simulation data is being overlaid. Addi-

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tionally, manipulating the object could affect the simulation and they could see the results in real time.

Discovering new interaction paradigms. Although some scientists might use AR/VR, and high resolution tiled displays to explore/visualize their datasets, they still rely on their computer and mouse to filter/analyze their data. The reason being is the lack of interaction techniques to manipulate their data in a meaningful way. The opportunity here is to investigate the right interaction paradigms that lend themselves to AR/VR and high resolution tiled displays for individual and remote collaborative data analysis and exploration.

3 Challenges

Simulation data transfer from the computing resources to novel display technologies. The data produced in Leadership Computing resources is of extremely high resolution and will exponentially grow as we move into exascale. As a result, transferring full resolution data from compute to display resources will not be feasible. Innovative data reduction techniques will need to be applied on the computing resources prior to transferring it to the novel display technologies.

There are additional challenges, depending on the display technology used. For example, bandwidth is extremely important, but latency and frame rates might not be (ex: high resolution tiled displays). On the contrary, high frame rates are essential in VR/AR, otherwise the immersive experience is lost. Another important consideration is rendering: For VR/AR, it might be more efficient to send simplified geometry to the device, and, as a result, to render it locally.

Therefore, we posit that future research needs to address when, how, and where the rendering happens in various conditions, from user-perspective frame-by-frame, to 360°stereo panoramas. Issues stemming from frame rate and latency must also be investigated. This is true whether the visualization is performed *in situ* or post hoc.

Interactive exploration of massive data. Massive data comes with massive challenges, and interaction is one of them. While stepping into the Mixed Reality world immerses the user into their data, interaction is still an unsolved problem. To put things in perspective, imagine looking at a enormous star dataset in VR. Which gesture would you use to reduce the data, or filter it? How would you apply data analysis visualization techniques, like streamlines? Are using voice commands appropriate, and if so, how does the audio communication take place? Furthermore, which interaction methodologies and tools are needed when collaboration is remote in these virtual spaces?

4 Timeliness, Maturity, Impact.

High-resolution tiled displays have been successfully used in scientific workflows for the scientific discovery process [6]. Tools like SAGE [5], have been deployed and used for collocated and remote scientific multi-disciplinary workflows, and provide opportunities to foster important DOE science collaborations and discoveries, with the technology being stable and mature. In like manner, Virtual Reality market is growing exponentially and expected to exceed $180 Billion by 2026 [3], with major investments across software and hardware development. Finally, in the AR space, Microsoft's HoloLens 2, ARKit (iPhone) and ARCore (Android) have democratized AR and brought it to the masses. We recognize that AR is not as mature as the aforementioned display technologies, however, we believe that AR will eventually become the next-generation display platform [7].

DOE has made significant investments in the advancement of state of the art scientific visualization tools (VTK, ParaView, VisIt, etc.), and therefore there is a huge opportunity to build upon and leverage them, in order to address the opportunities and challenges discussed in this white paper.

Moreover, DOE scientists have been working on *in situ* and in transit methodologies to avoid expensive I/O operations (SENSEI [1], ASCENT [4]). These technologies are mature and have been demonstrated at scale with well-known simulation codes. Taking advantage of their existing capabilities, and code integration with simulations, we can leverage them to deliver data efficiently to novel display technologies. As a result, existing *in situ* instrumented scientific applications will be immediately available for use with these new display technologies and enable new modalities of interaction, without any additional effort from the application developers.

5 Conclusion

In this white paper we identified the unique opportunities that novel display technologies, like Virtual and Augmented Reality Displays, and High Resolution tiled displays will unlock for DOE mission science. There will be challenges involved, but we believe these technologies will make a significant impact on scientific discovery. We envision a future where scientists collaborate easier, look at their data more naturally, and interact with it more intuitively. With great–exascale–power comes great–visualization–responsibility.

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